B Physics at the Tevatron

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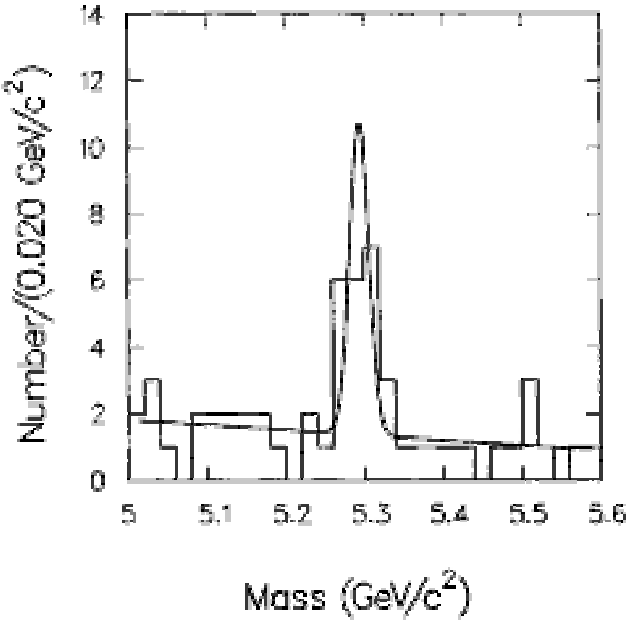
11 July 2003
Physics at LHC Conference
Prague, Czech Republic

- Introduction
- Startup of Run II
- B Hadron Producers
- B Physics at the Tevatron
- Selected Run II Results from CDF & D0
- Conclusion

A Brief History of Time

First fully reconstructed B mesons at a hadron collider:

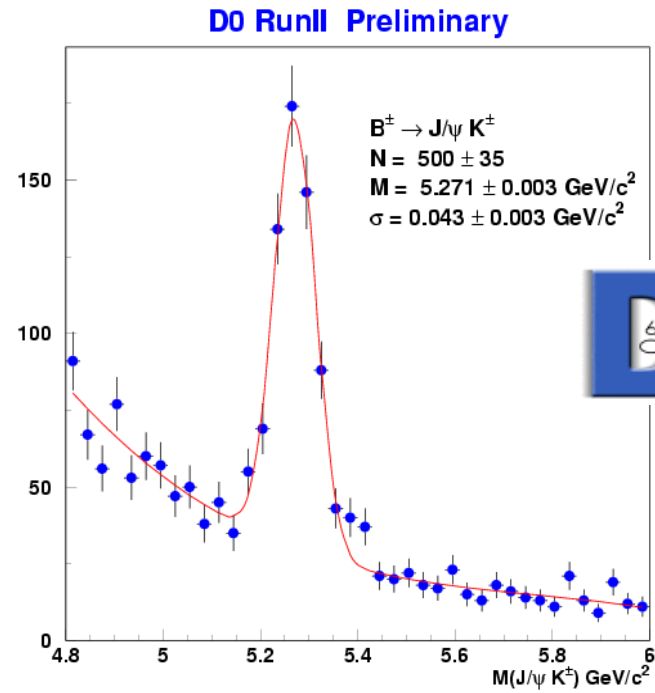
$B^+ \rightarrow J/\psi\ K^+$

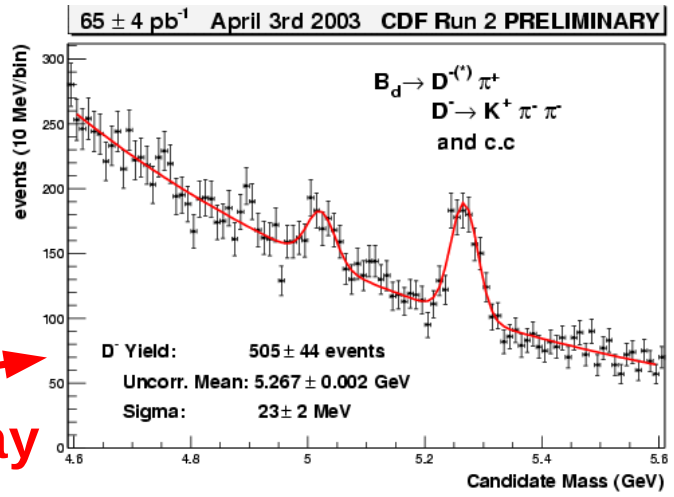


CDF 1992 (2.6 pb^{-1})

PRL 68, 3403 (1992)

Nowadays





Fully hadronic B decay

Fermilab

Some more history:

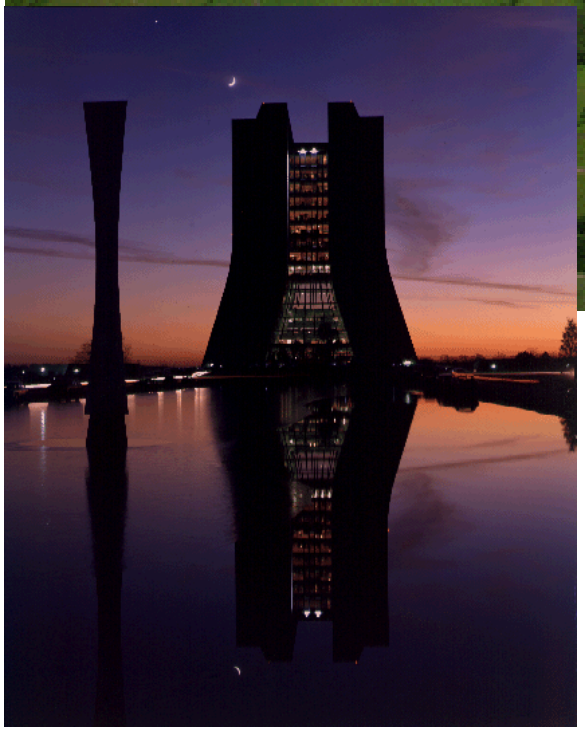
1967: Fermilab founded

1978: Laboratory decision to build pp= collider

1985: First collisions in Tevatron

Run I: 1992-1996 data taking period

Run II: Started March 01 after major upgrades of CDF & D0



The Fermilab site

The Upgraded Tevatron

E_{CMS} = 1.96 TeV (was 1.8 TeV)

Main Injector (150 GeV proton storage ring) replaces Main Ring

Luminosity goal: 1-2x$10^{32}$$cm^{-2}$$s^{-1}$ (x10 - Run I)

Bunch crossing time: 396 ns (x10 - Run I)

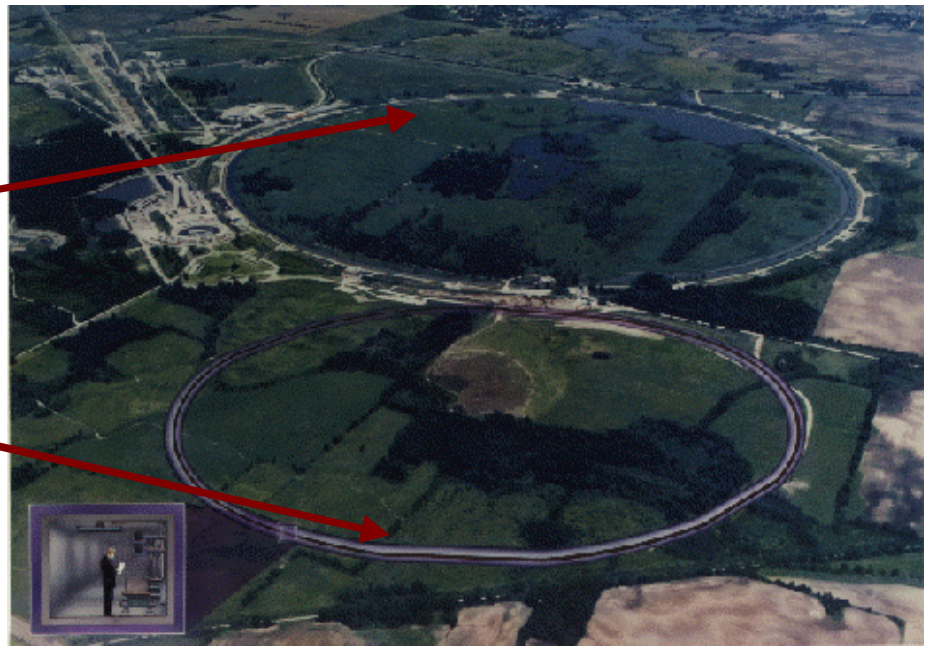
(132 ns upgrade indefinitely postponed)

36x36 bunch operation (was 6x6)

Presently: ~1-2 interaction/bunch crossing (expect up to 10 in future)

Interaction region:

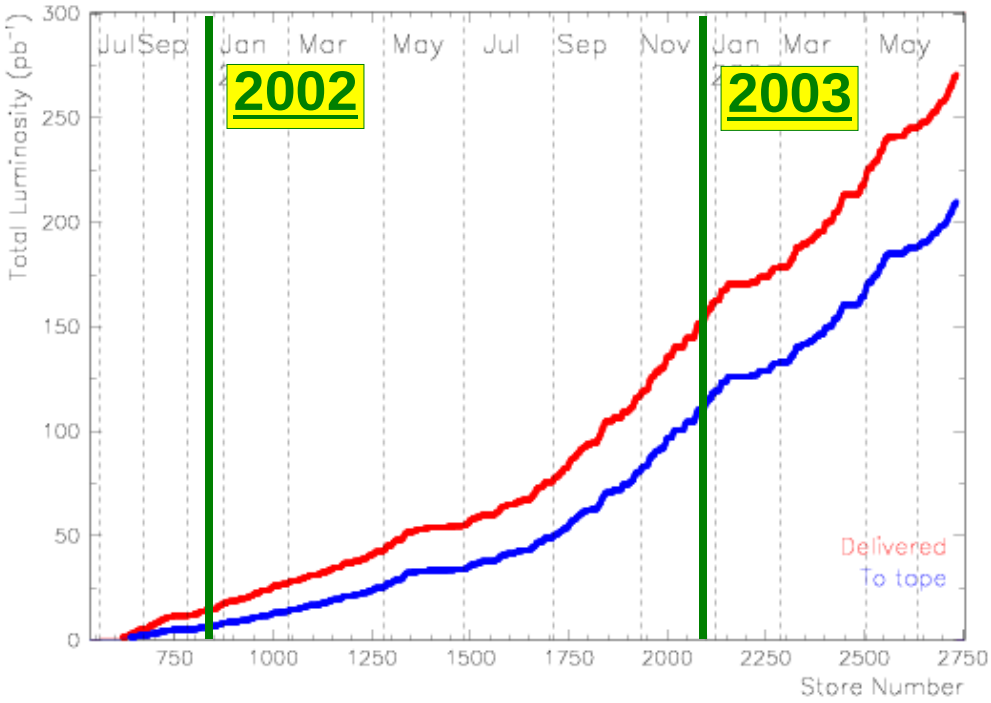
- ~ 30 μm transverse size
- ~ 30 cm long,



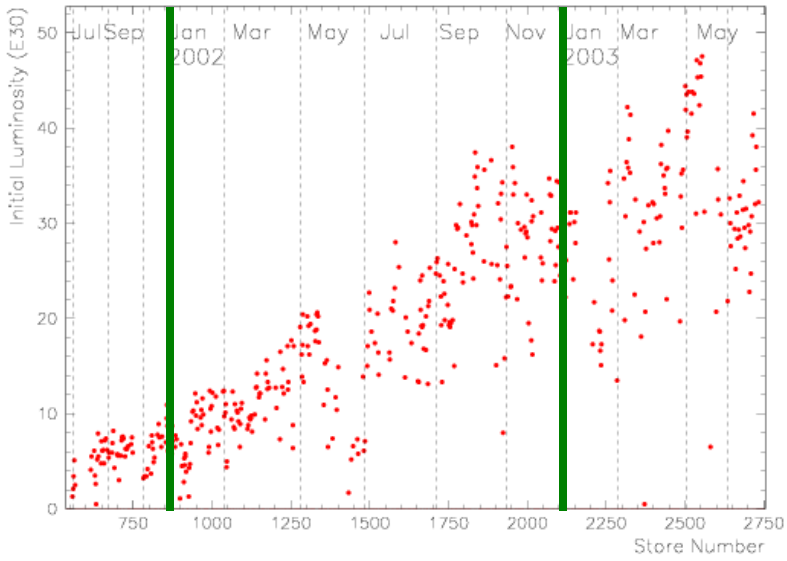
Run II started March 2001

The Startup of Run II

Tevatron operations:



Initial luminosities:
Peak so far: 4.7×10^{31} cm^{-2}s^{-1}



Delivered so far: ~270 pb^{-1}
Recorded to tape: ~210 pb^{-1}

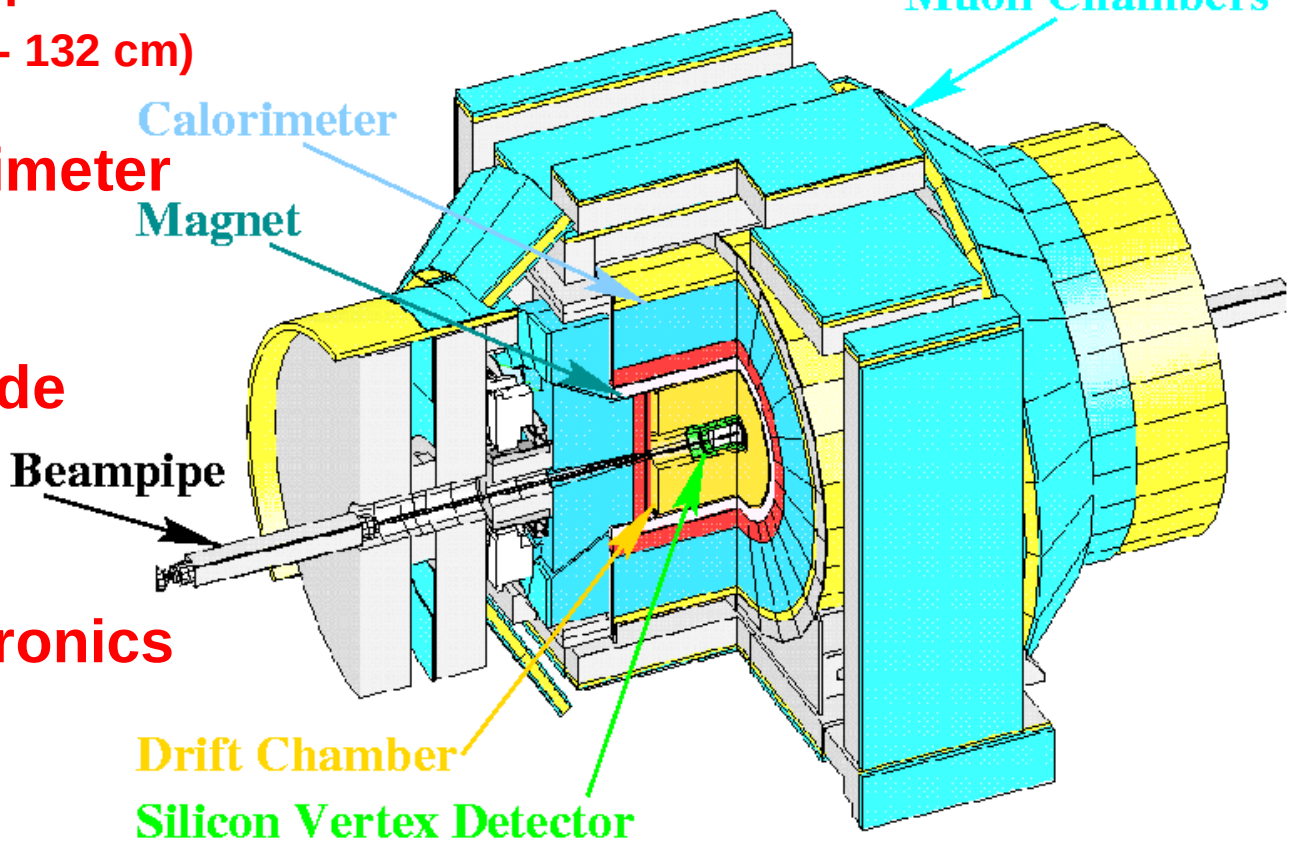
Still factor 2 below nominal

Usable for analyses: ~140 pb^{-1} (most results shown use ~70 pb^{-1})
Data taking efficiency: ~80-95%

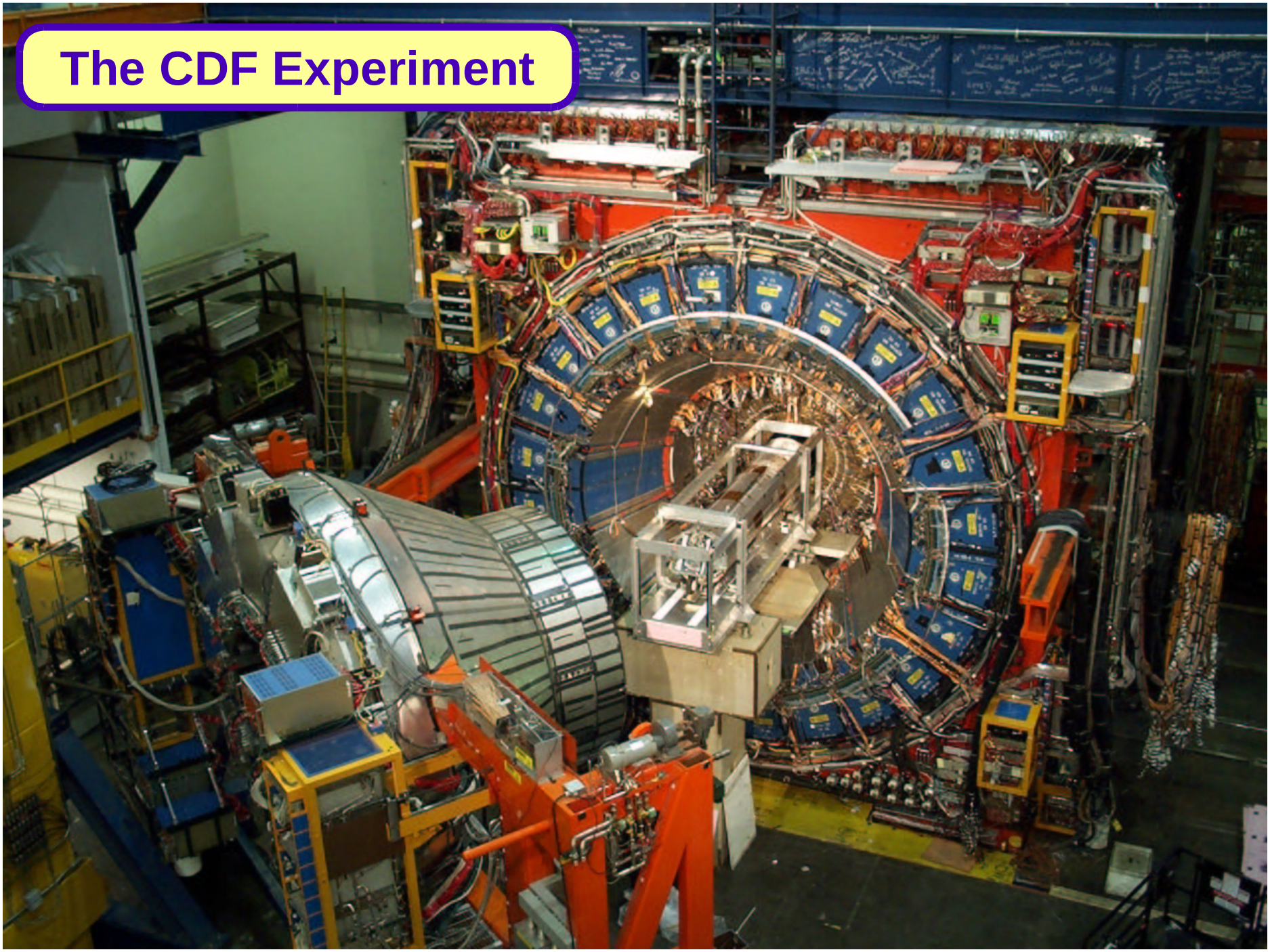
The Startup of Run II

The Upgraded CDF Detector:

- **Tracking upgrade:**
  - **Silicon:**
    Beampipe layer + 5 layers + 2/1 outer (forward) layers (radial 1.5 - 28 cm)
    Full coverage of luminous region; Si tracking up to $|\eta| < 2$
  - **Central Outer Tracker:**
    30,200 sense wires (44 - 132 cm)
    96 dE/dx samples
- **New endplug calorimeter**
- **Improved muon coverage**
- **Trigger/DAQ upgrade**
  - **Fully pipelined**
  - **All digital (132 ns)**
  - **Silicon trigger at L2**
- **New frontend electronics**
- **Time-of-flight system**



The CDF Experiment

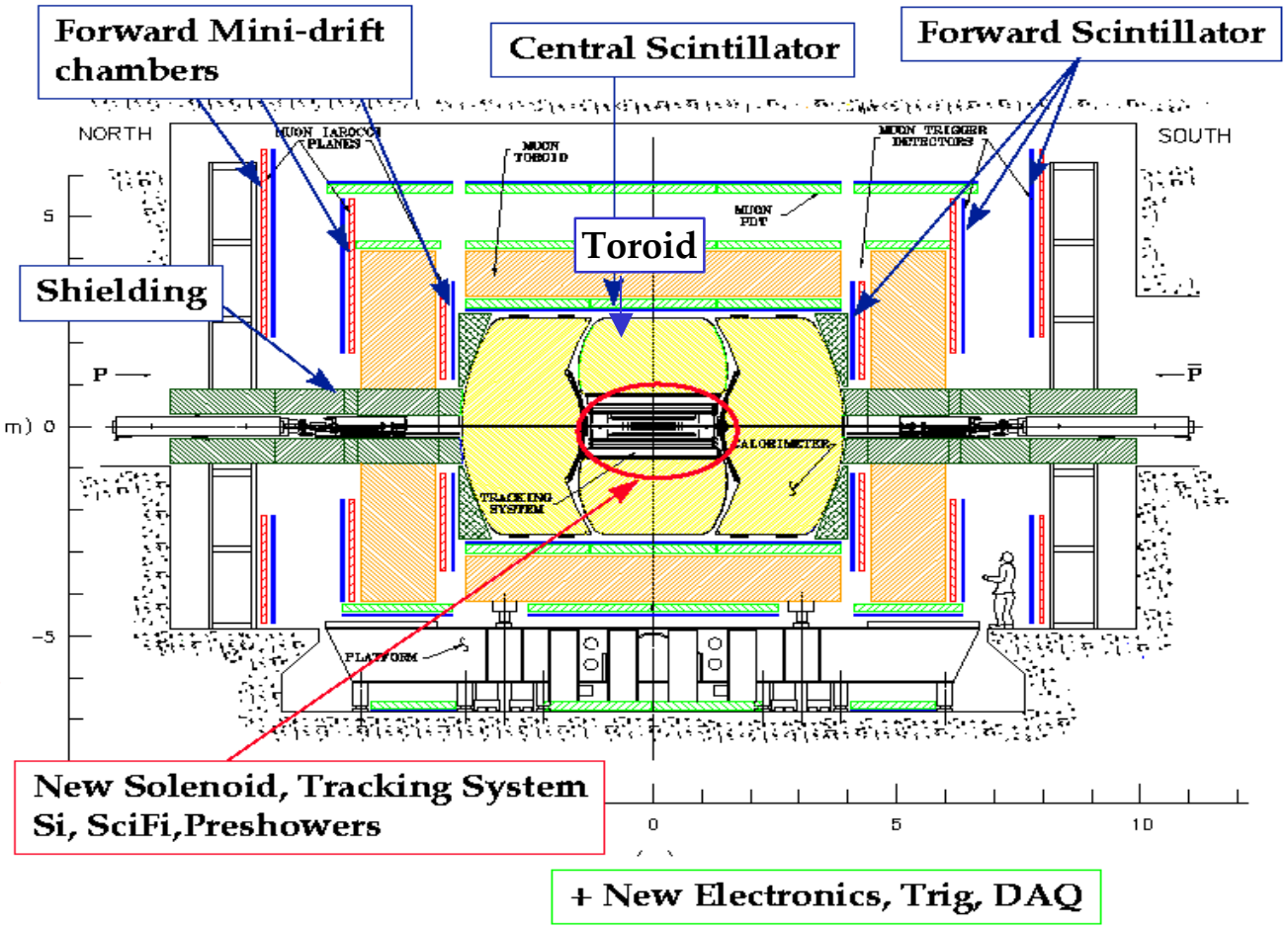


The Startup of Run II

The Upgraded D0 Detector:

What's new at D0:

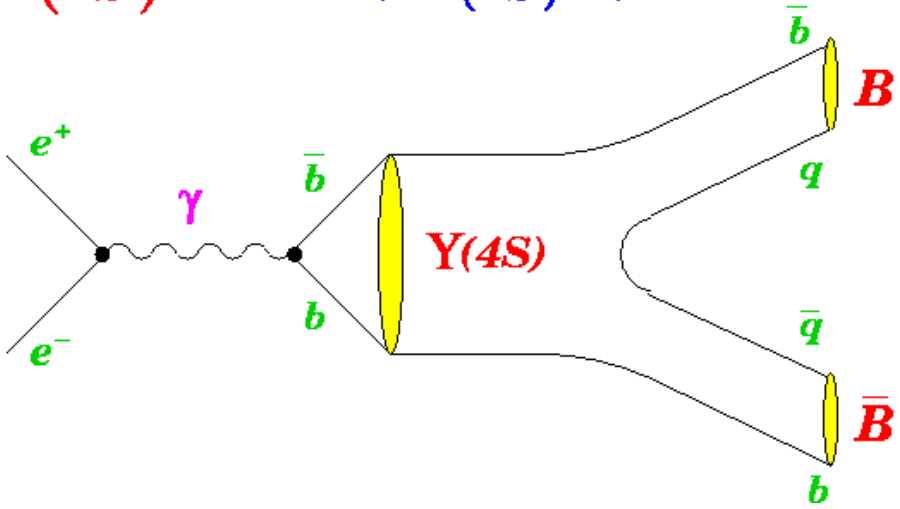
- **New detector elements:**
  - solenoid, silicon tracker, fiber tracker
  - new preshower detector
- **Improved muon system**
- **Enhanced trigger system**
- **Extra shielding around beamlines**



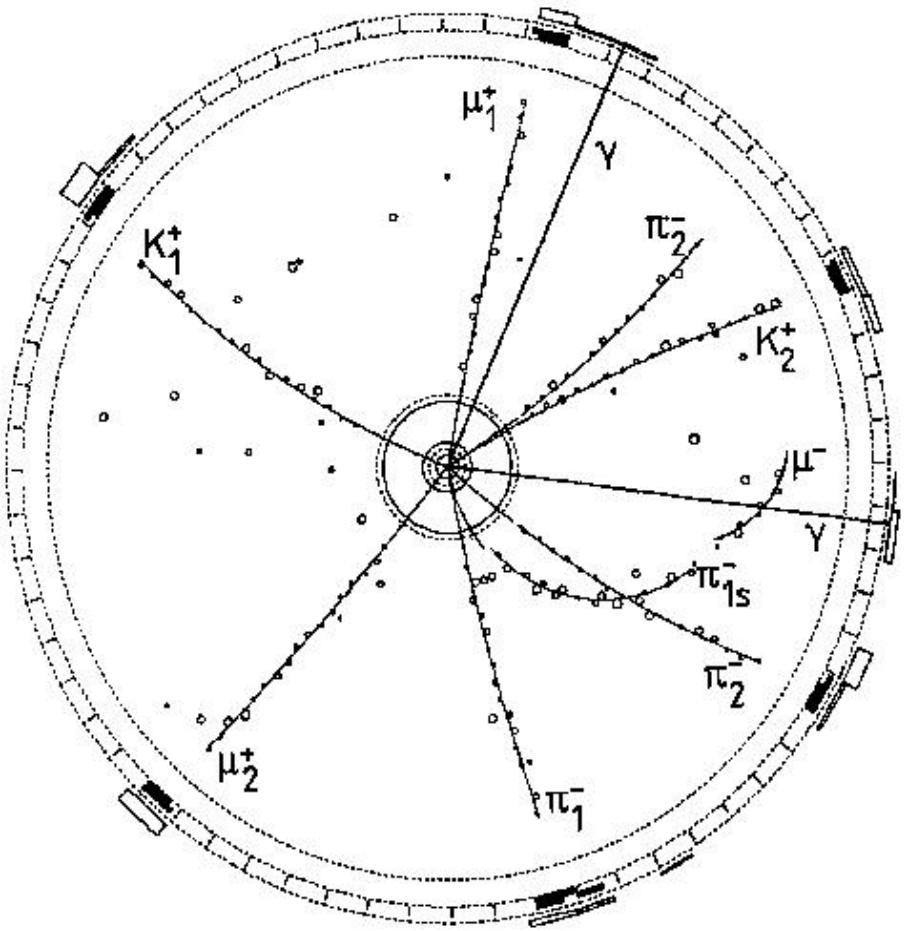
B Hadron Producers

Overview of B Hadron Producers:

$\Upsilon(4S)$: $e^+e^- \rightarrow \Upsilon(4S) \rightarrow B\bar{B}$



ARGUS:



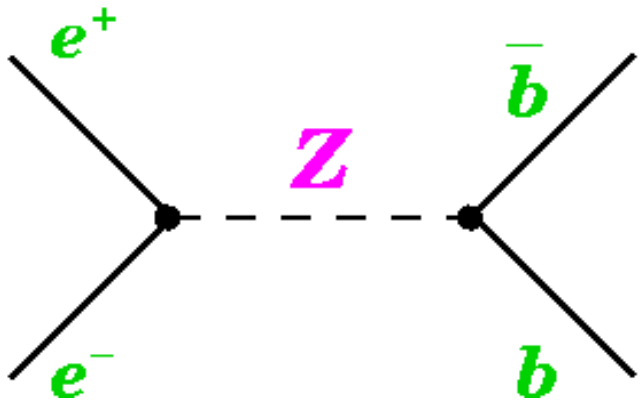
The Players:

ARGUS & CLEO (Pioneers)

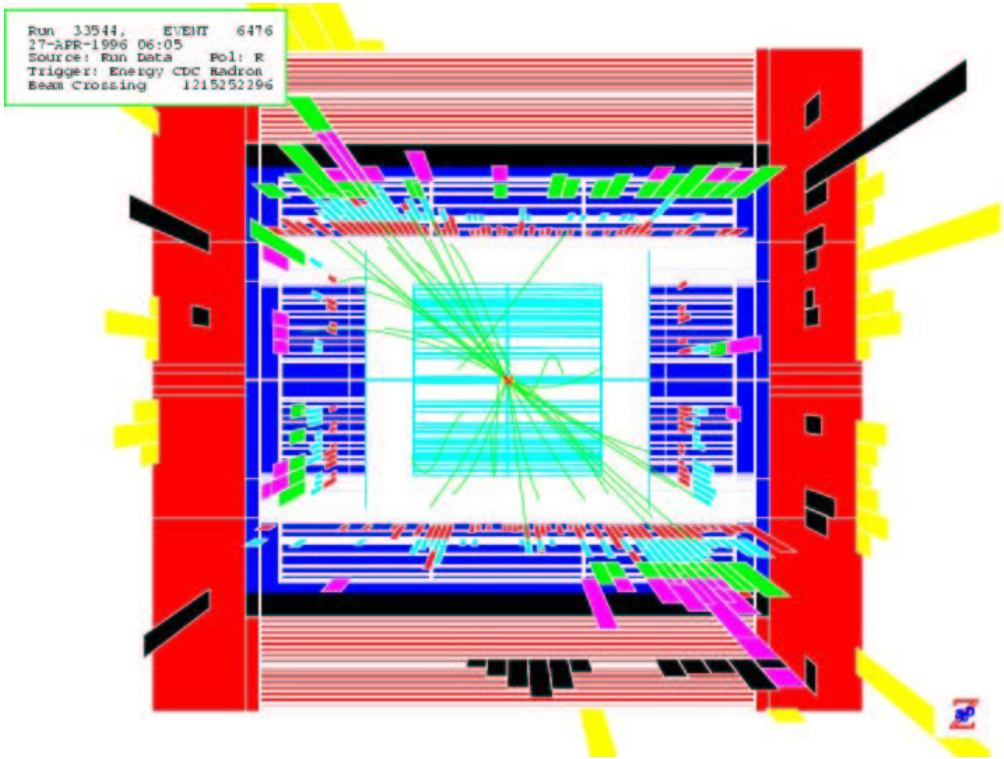
BaBar & Belle (B Factories)

B Hadron Producers

Z^0: $e^+ e^- \rightarrow Z^0 \rightarrow b\bar{b}$



SLD:



The Players:

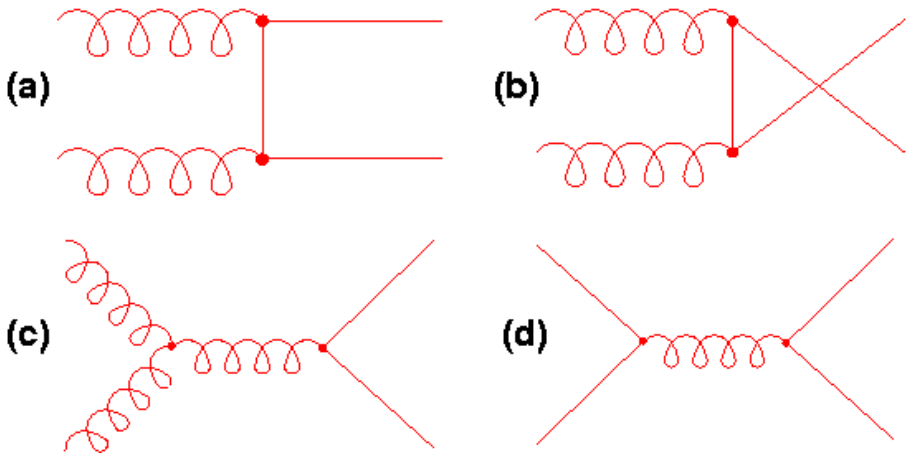
ALEPH, DELPHI, L3, OPAL

SLD

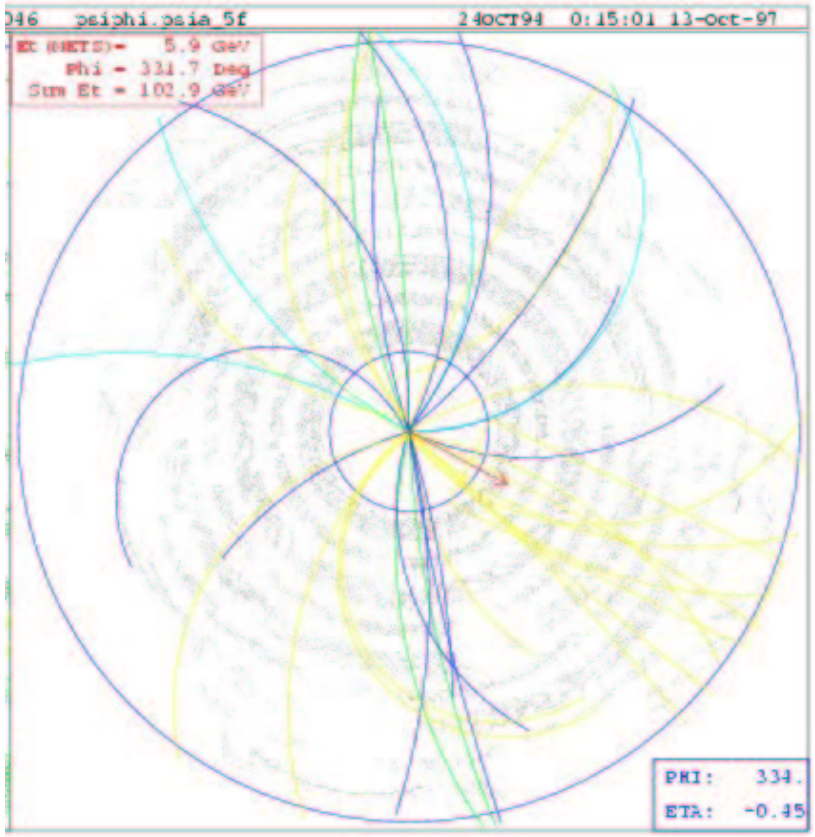
B Hadron Producers

Tevatron: $p\bar{p} \to b\bar{b}X$

- Lowest order $\mathcal{O}(\alpha_s^2)$ diagrams for $b\bar{b}$ production
  - (a)-(c) gluon-gluon fusion
  - (d) quark-antiquark annihilation



CDF:



The Players:

CDF & D0

Other B producers: Hera-B, FNAL fixed target

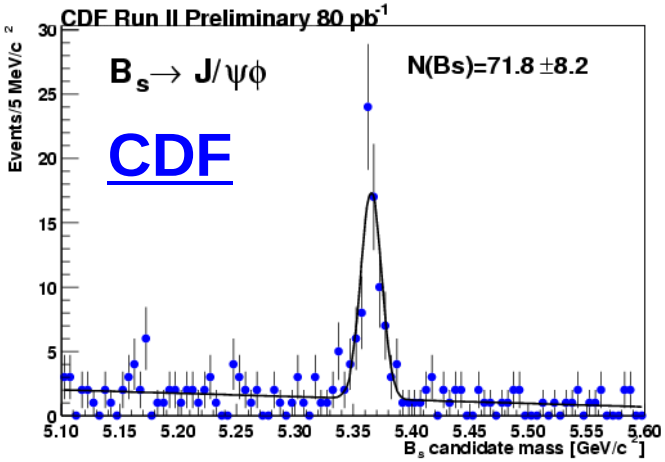
The Future: Atlas, CMS, LHCb, BTeV

Why do we have so many (✈❃☹➶✌♒❗✪) B factories these days?

Why the (✈❇☹➶✌♒❗✪)
do we want to do
B physics at Fermilab?

B Physics at the Tevatron

- Advantages of B Physics at the Tevatron:
  - All B hadrons are produced: B^0, B^+, B_S^0, B_c^+, Λ_b^0
  - Enormous cross section
    - at $\Upsilon(4S)$: $\sigma(B\bar{B}) \approx 1\ nb$
    - at Tevatron: $\sigma(p\bar{p} \to b\bar{b}) \approx 50\ \mu b$
  - $\approx 5 \cdot 10^9\ b\bar{b}$ pairs produced in Run I during 1992-96



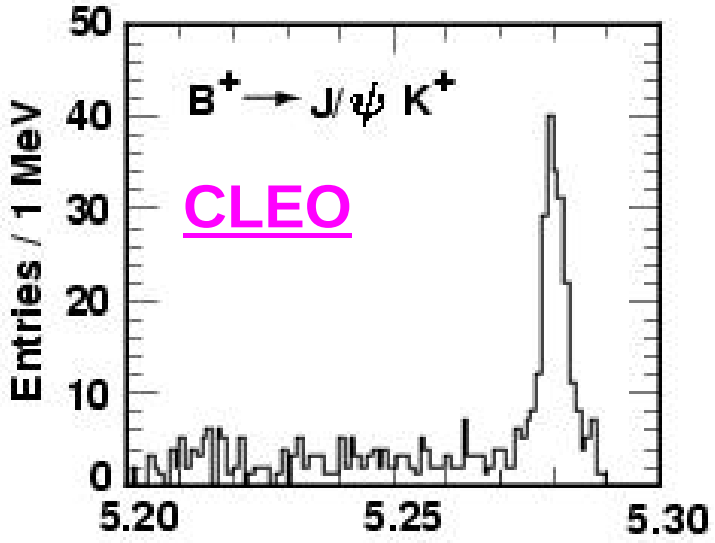
- Compare yield of B mesons:

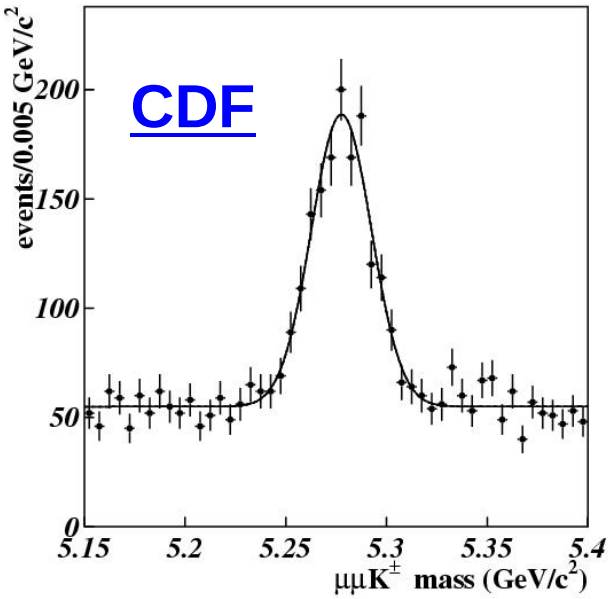
CLEO: $\mathcal{L} = 3100\ pb^{-1}$

$N(B^+ \to J/\psi K^+) = 198 \pm 15$

CDF: $\mathcal{L} = 110\ pb^{-1}$

$N(B^+ \to J/\psi K^+) = 998 \pm 51$





B Physics at the Tevatron

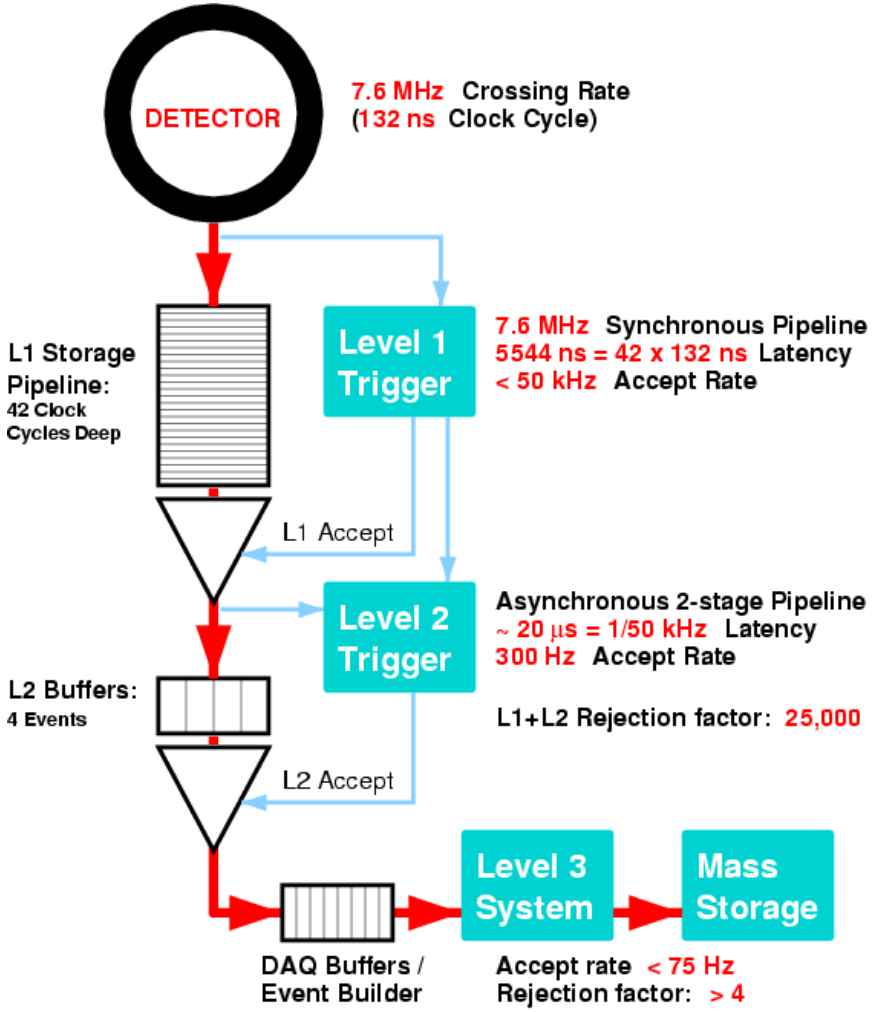
Comparison with charm production

- **Total inelastic cross section:**

  $\sigma(\text{total}) / \sigma(b) \sim$ **1000**

➔ **It's all about the trigger!**

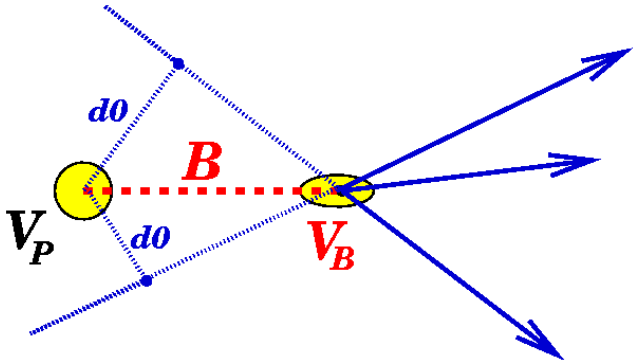
CDF's 3-level trigger system:



B Trigger at CDF

- **Run I:** B trigger based on leptons
  - ➔ Dilepton trigger: J/ψ, mixing
  - ➔ Single lepton: semileptonic B decays
- **Run II:** Hadronic track trigger

(exploit 'long' B lifetime)

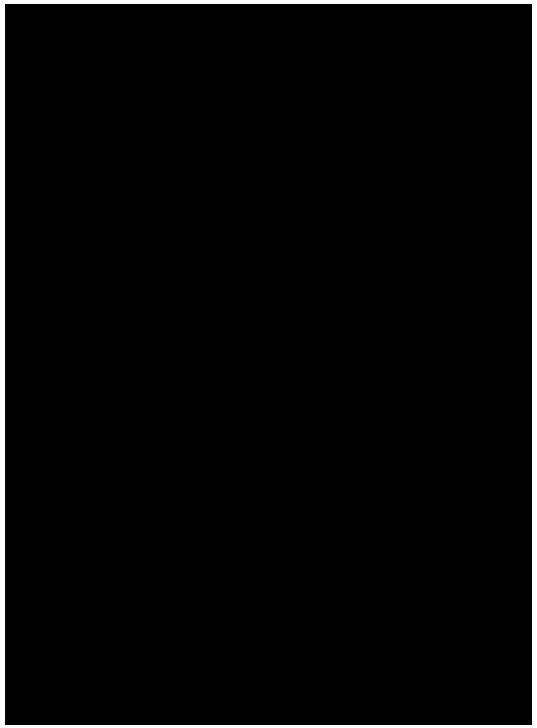


Level 1: Fast track trigger (XFT) finds charged track with p_T > 1.5 GeV/

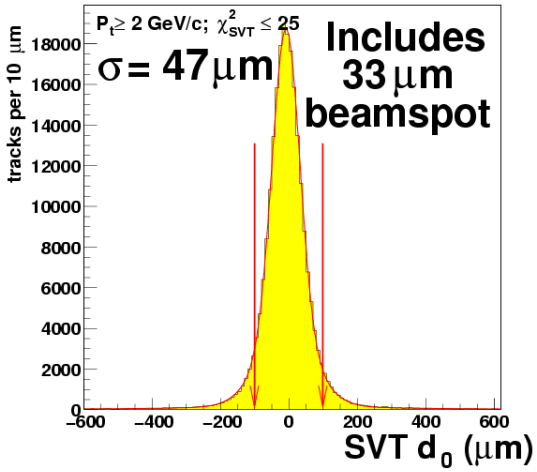
Level 2: Link tracks into silicon; require track impact parameter > 100 μm (SVT)

Access to hadronic B decays
=> B physics program fully competitive with B factories

Example: Run I single electron trigger

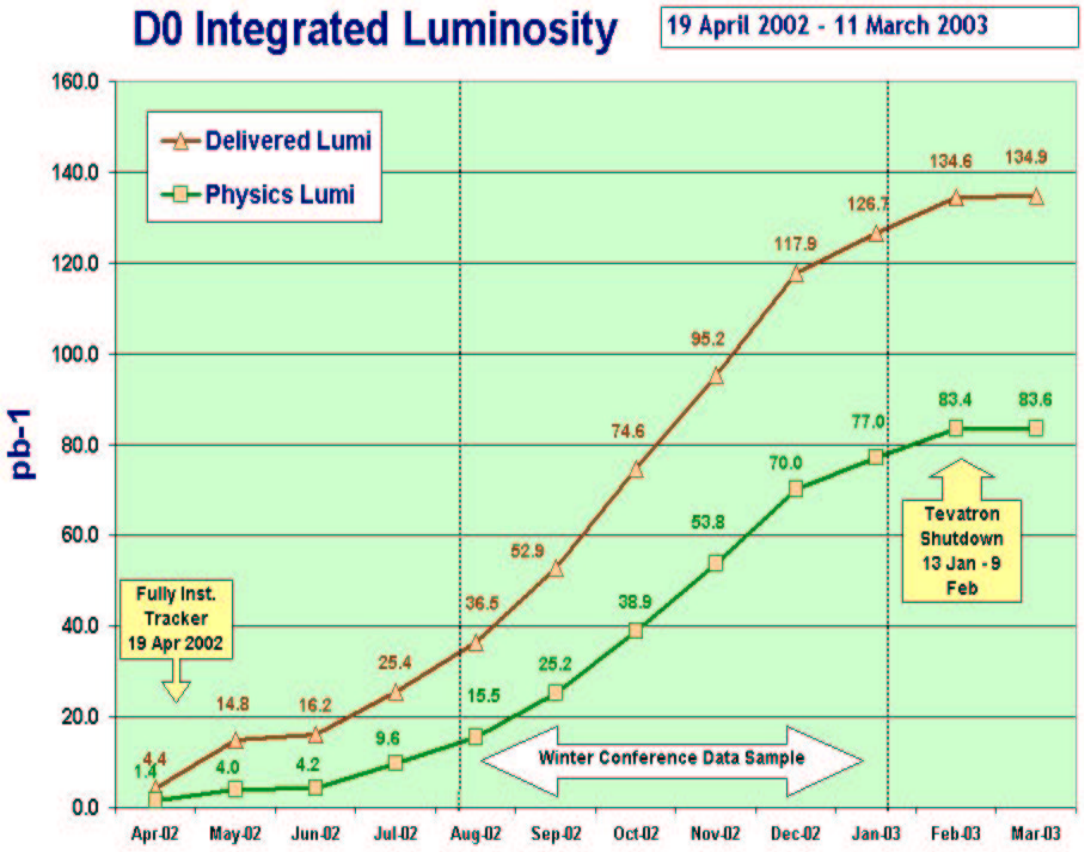


SVT impact parameter resolution:



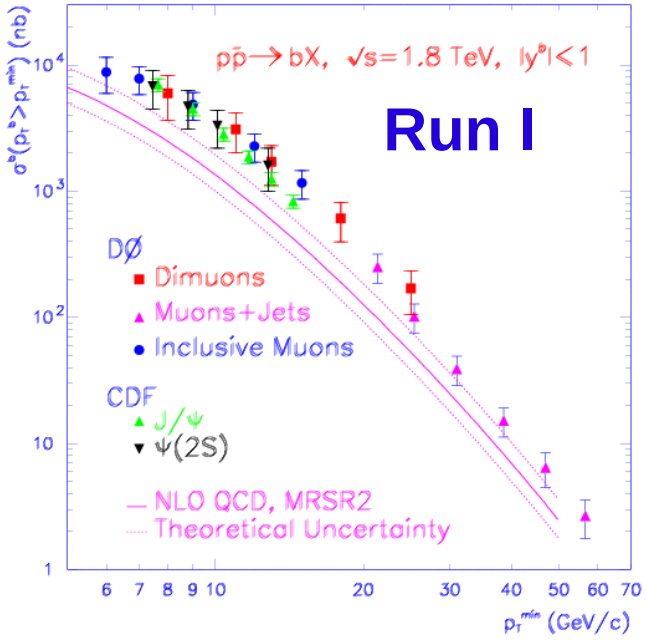
Trigger at D0

- **Run II:** B trigger
  - ➔ Dilepton trigger: J/ψ, mixing
  - ➔ Single lepton: semileptonic B decays
  - ➔ Commissioning of new hadronic track trigger (note, no pipeline)
- **Current trigger rates:**
  - L1 rate: 1 kHz
  - L2 rate: 600 Hz
  - L3 rate: 50 Hz
- Data taking efficiency: ~85% overall

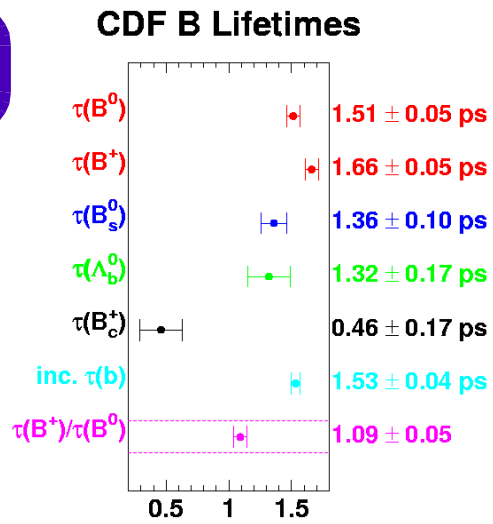


B Physics in Run I

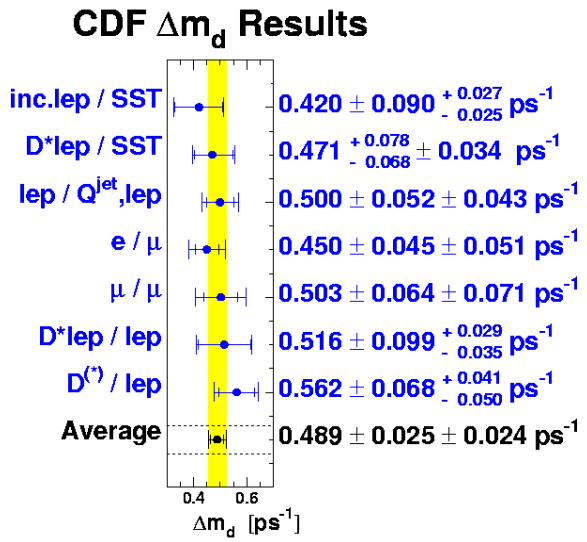
Successful B physics program at Tevatron in Run I:



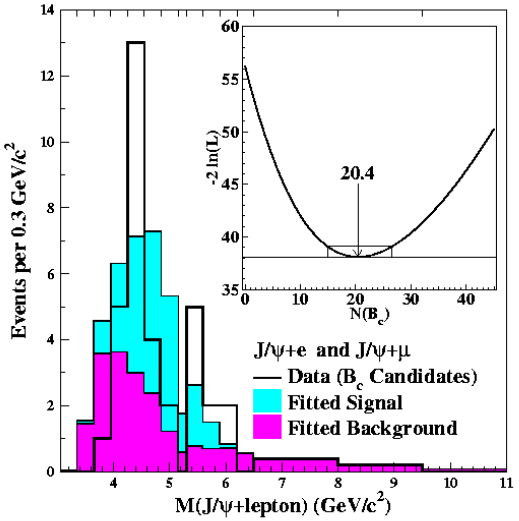
B Cross Sections



B lifetimes



B mixing



Discovery of B_C meson

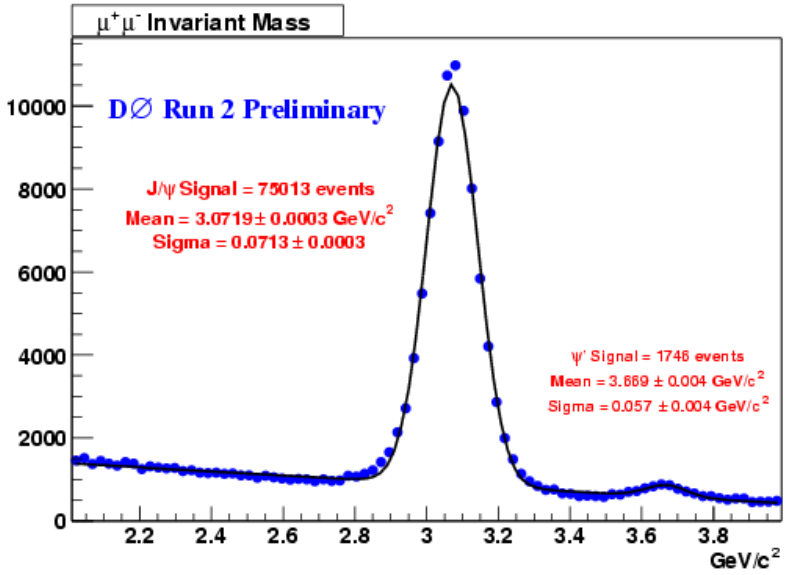
Evidence for $\sin 2\beta \neq 0$

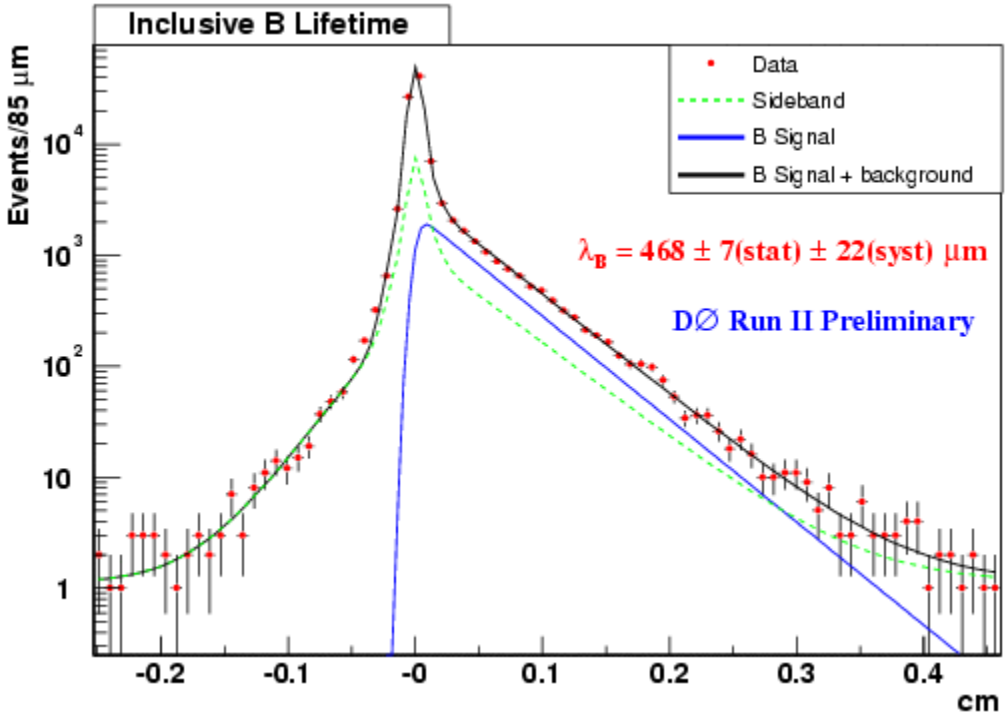
Selected Run II Results

Average B Lifetime:

J/ψ → μμ signal: ~75,000 events (40 pb^{-1})

Average B lifetime from B -> J/ψ X:





$\tau(b) = (1.561 \pm 0.024 \pm 0.074)$ ps

Selected Run II Results

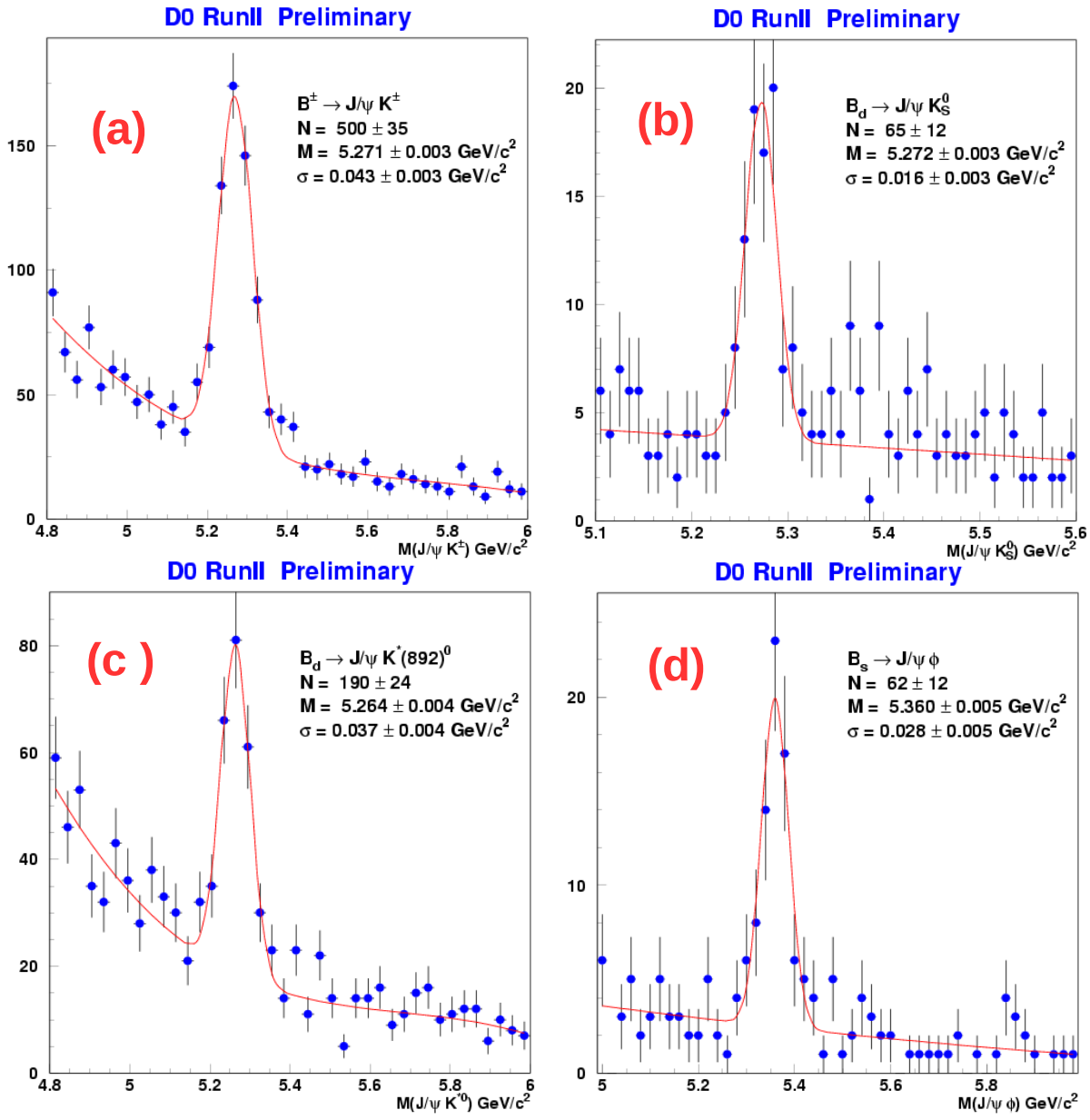
Exclusive B Decays:

(a) $B^+ \rightarrow J/\psi\, K^+$ (N=500)

(b) $B^0 \rightarrow J/\psi\, K_S$ (N=65)

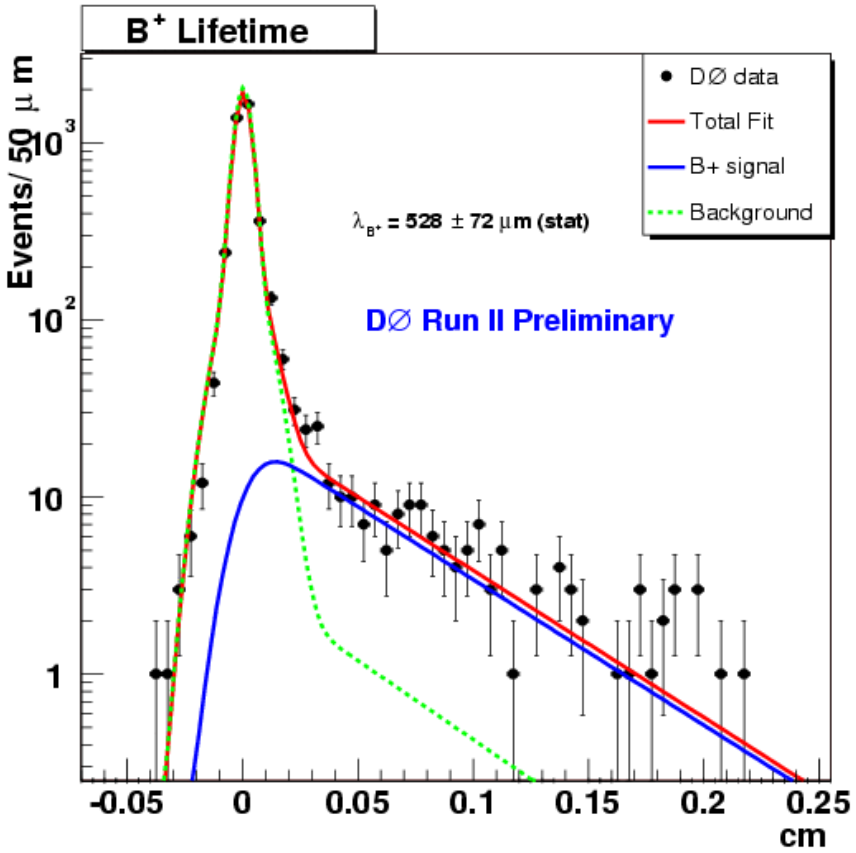
(c) $B^0 \rightarrow J/\psi\, K^*$ (N=190)

(d) $B_S \rightarrow J/\psi\, \phi$ (N=62)



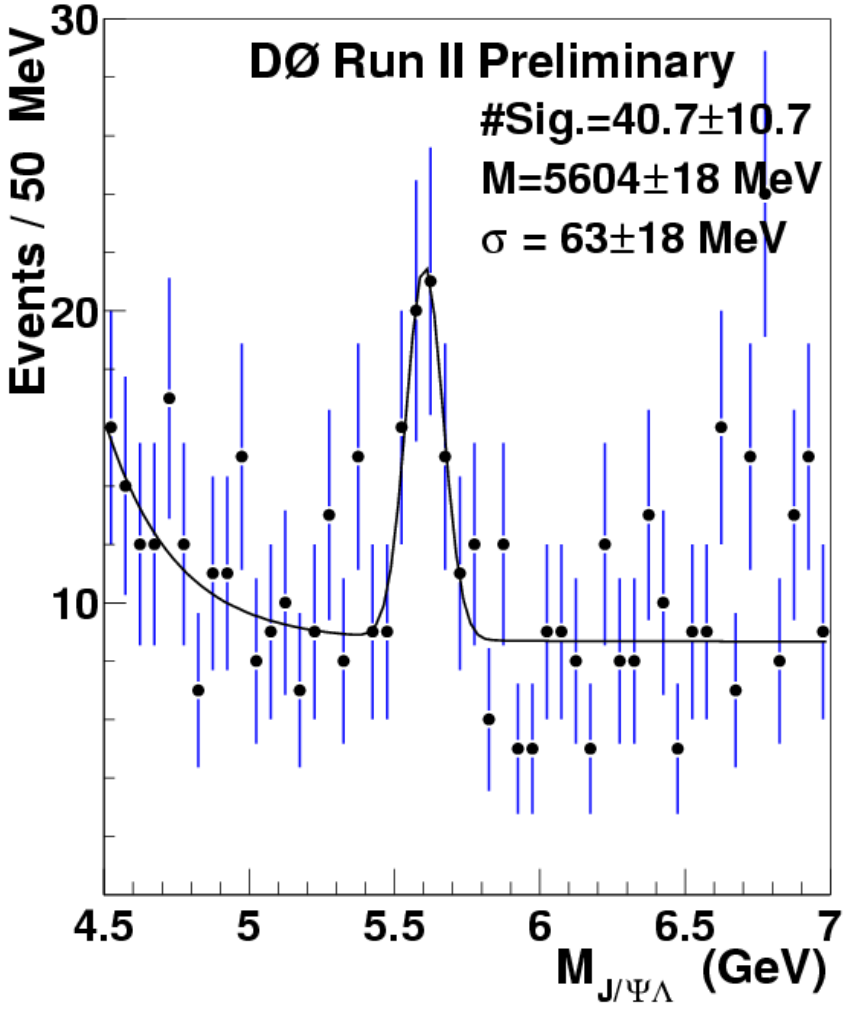
Selected Run II Results

B^+ Lifetime: $B^+ \rightarrow J/\psi\, K^+$:



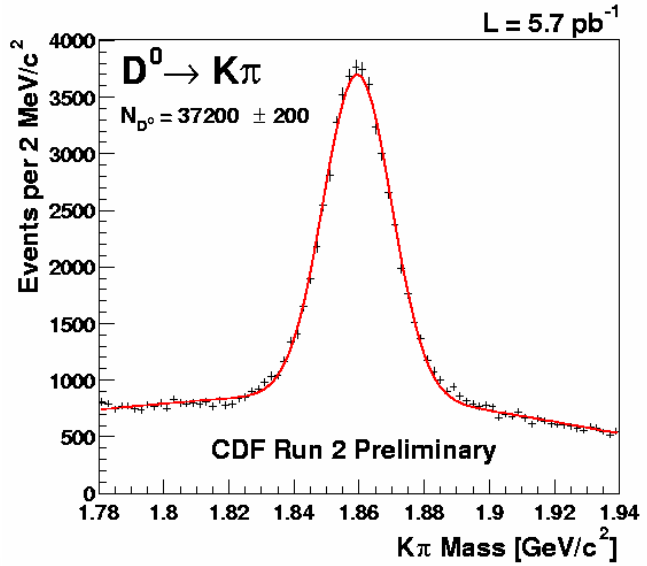
$\tau(B^+) = (1.76 \pm 0.24)$ ps (stat.)

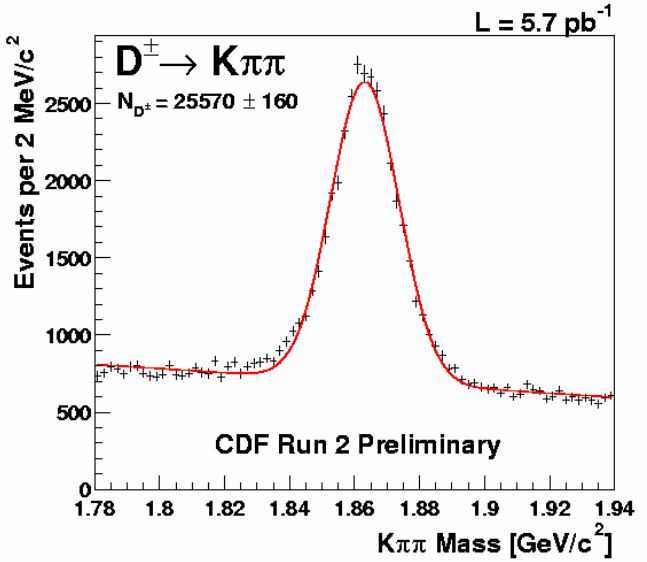
B baryons: $\Lambda_b \rightarrow J/\psi\, \Lambda$:



CDF Run II Results

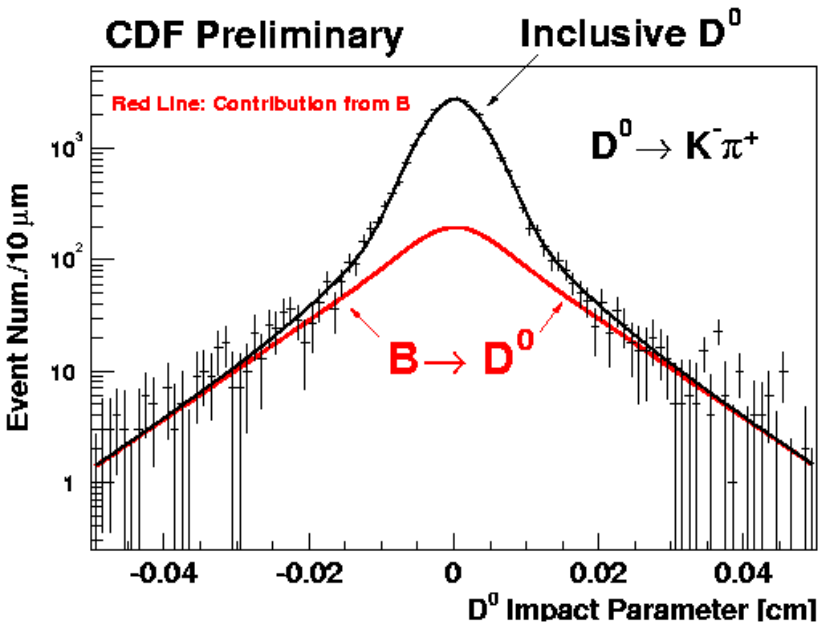
Physics signals from 2-track hadronic trigger:





Where does charm come from?

- Prompt charm: $d_0 = 0$
- B -> charm: $d_0 \neq 0$



CDF is collecting large amounts of direct charm!

Selected Run II Results

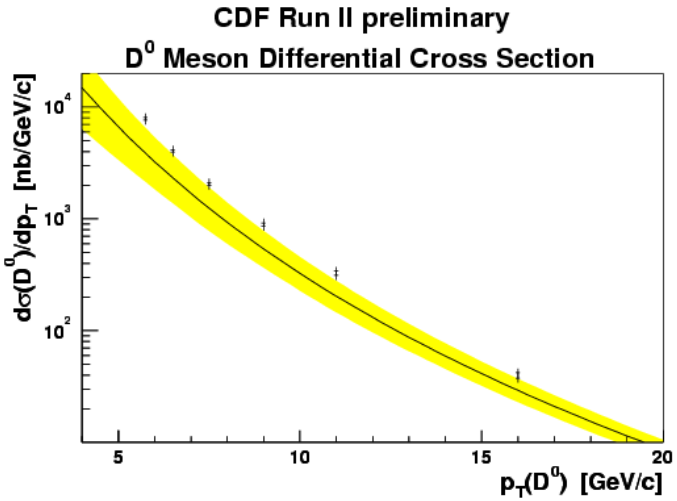
Direct charm cross sections:

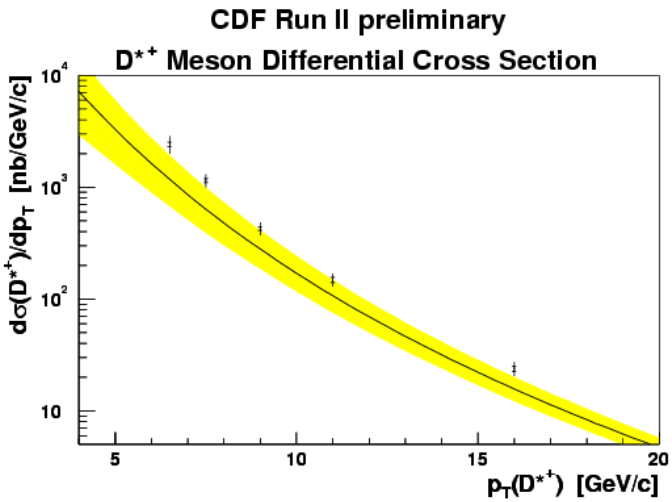
$\sigma(D^0, p_T > 5.5\ GeV) =$
$(13.3 \pm 0.2 \pm 1.5)\ \mu b$

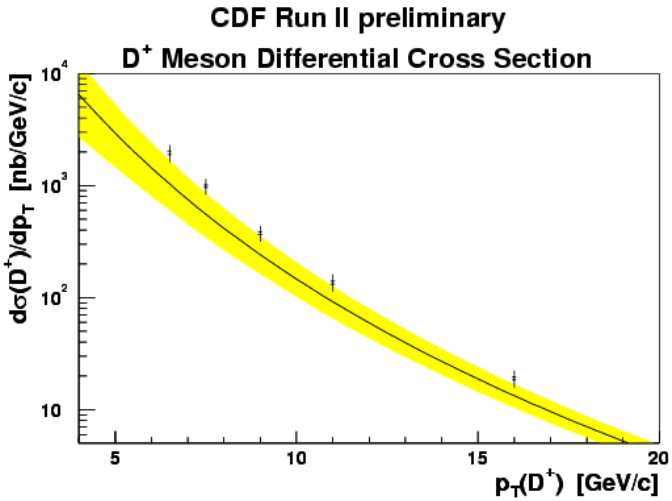
$\sigma(D^{*+}, p_T > 6.0\ GeV) =$
$(5.2 \pm 0.1 \pm 0.8)\ \mu b$

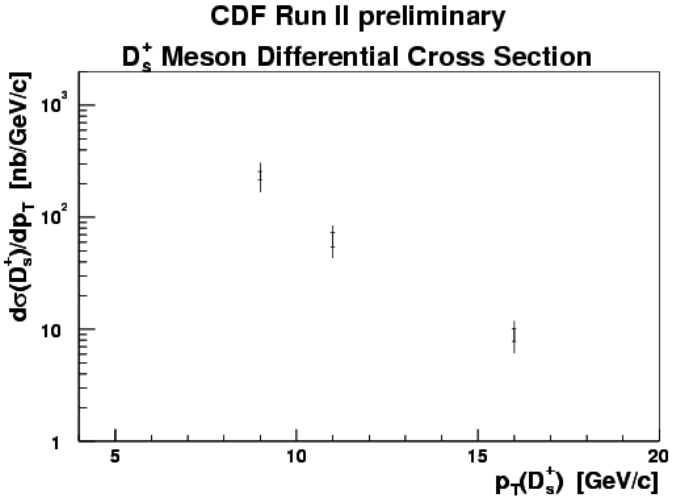
$\sigma(D^+, p_T > 6.0\ GeV) =$
$(4.3 \pm 0.1 \pm 0.7)\ \mu b$

$\sigma(D_S, p_T > 8.0\ GeV) =$
$(0.75 \pm 0.05 \pm 0.22)\ \mu b$







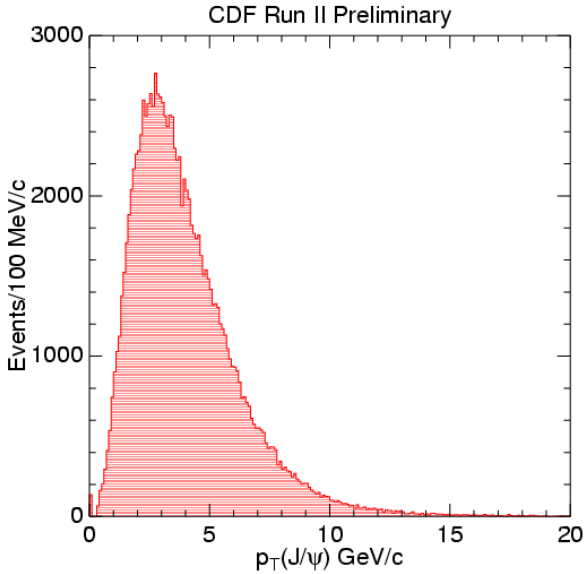


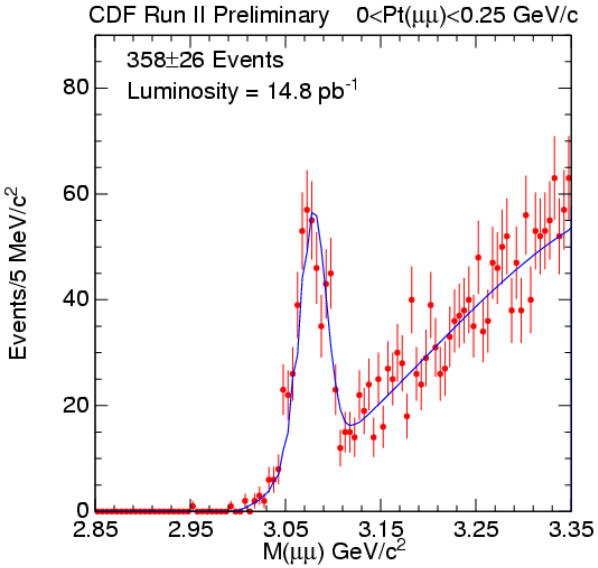
Selected Run II Results

J/ψ cross section:

Lower muon threshold of p_T > 1.5 GeV/c in Run II

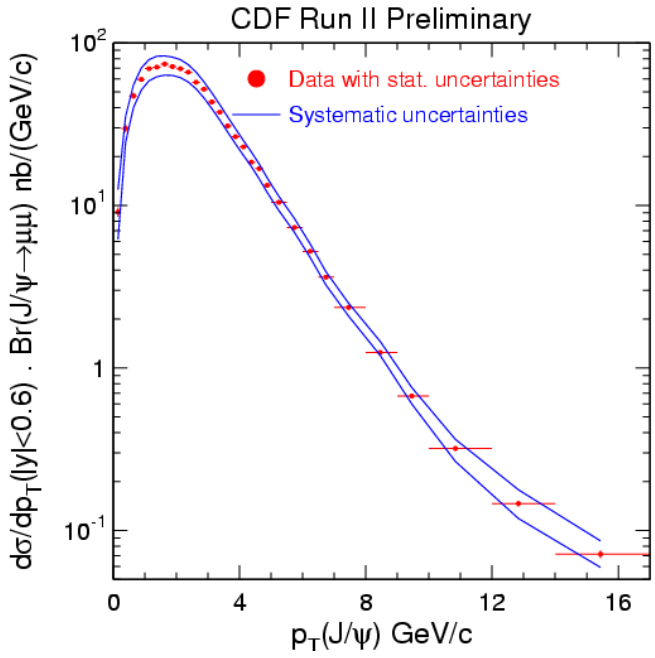
=> measure J/ψ cross section down to p_T of zero at hadron collider





$\sigma(p_T > 0.0$ GeV, $|\eta|<0.6) =$

(240 ± 1 ± 35/28) nb



Selected Run II Results

Reconstruction of fully hadronic B decays:

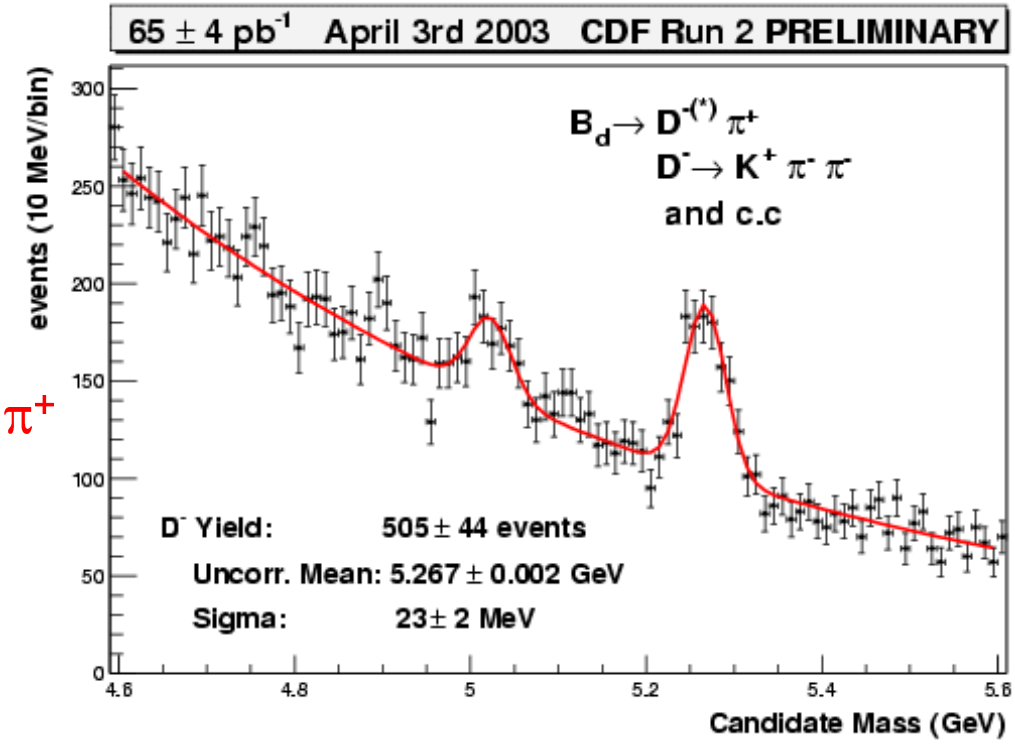
Measurement of B branching ratios:
Compare search mode to kinematically similar mode:

$$\frac{\sigma_b \cdot f_S \cdot BR(B_S^0 \to D_S^- \pi^+)}{\sigma_b \cdot f_d \cdot BR(B^0 \to D^- \pi^+)} = \frac{\epsilon_{B^0} \cdot N_{B_S^0} \cdot BR(D^- \to K^- \pi^+ \pi^+)}{\epsilon_{B_S^0} \cdot N_{B^0} \cdot BR(D_S^- \to K^- K^+ \pi^+)}$$

Advantage: Cancellation of

- σ_b
- systematics in trigger and reconstruction efficiency

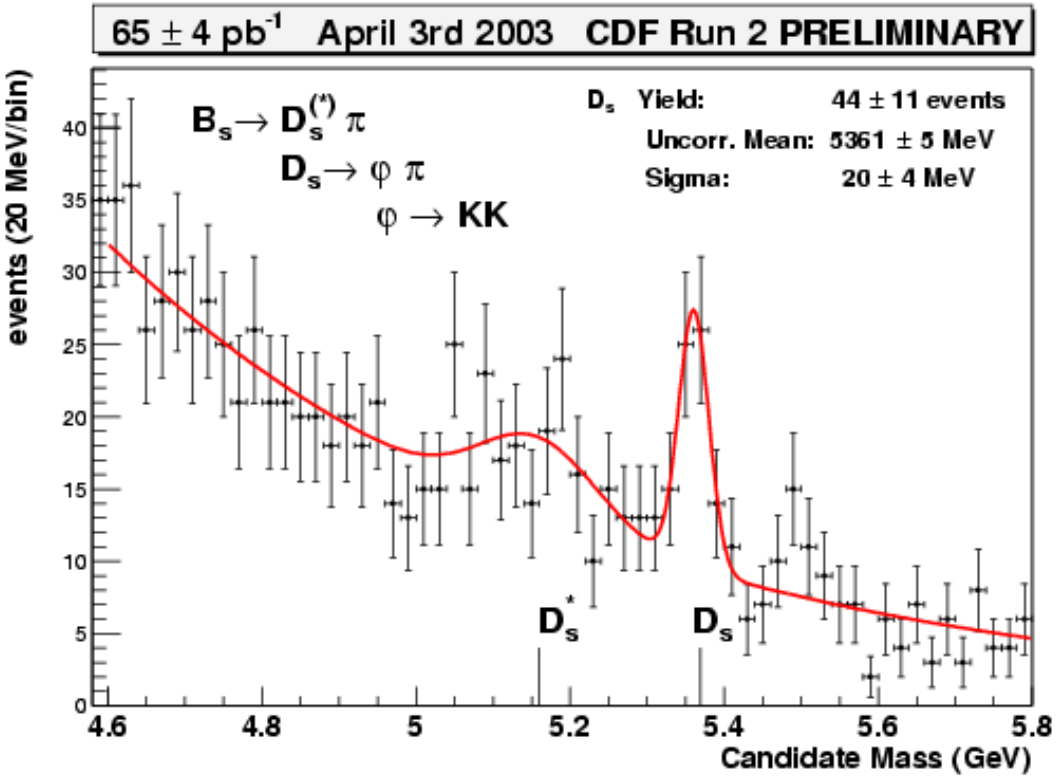
Normalization mode: $B^0 \to D^- \pi^+$



Selected Run II Results

Reconstruction of hadronic B decays:

First observation of $B_S^0 \rightarrow D_S \pi^+$

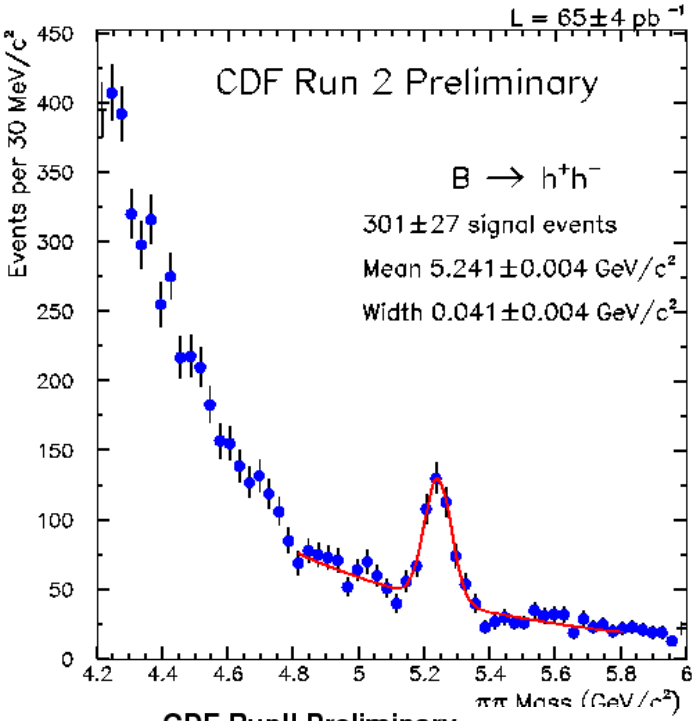


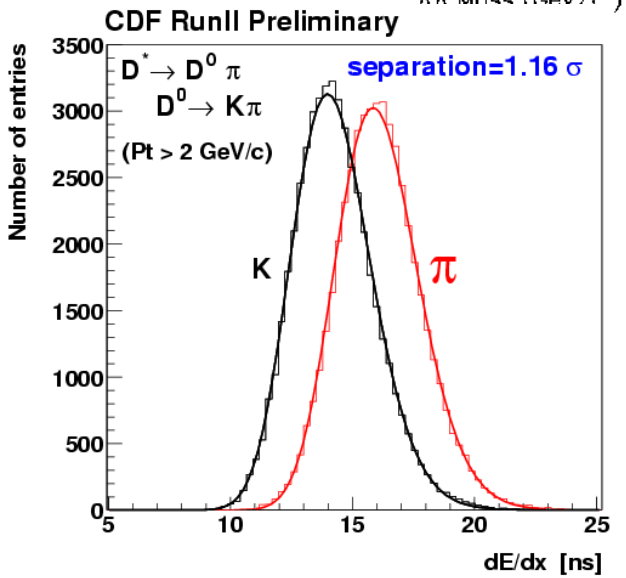
$$\frac{f_s \times BR(B_s \rightarrow D_s \pi)}{f_d \times BR(B_d \rightarrow D \pi)} = 0.44 \pm 0.11(stat) \pm 0.11(BR) \pm 0.07(syst)$$

Selected Run II Results

Two-Body Charmless B decays:

- Use hadronic track trigger
- Find ~ 300 events in 65 pb^{-1}
- S : N = 2 : 1 (expected 1:1)
- Signal is mix of B^0 / B_S^0 → ππ, Kπ, KK
- Use dE/dx & kinematics to disentangle
- BR(B^0 → ππ) / BR(B^0 → Kπ) =
  = 0.26 ± 0.11 ± 0.055
- Significant B_S^0 -> KK contribution:
  90 ± 17 ± 17 events
- Fraction of B^0 -> Kπ: 0.53 ± 0.06
  B^0 -> ππ: 0.14 ± 0.05
  B_S^0 -> KK: 0.32 ± 0.06
  B_S^0 -> Kπ: 0.01 ± 0.04





Conclusions

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- Start-up of Run II
- Tour of B producers
- How to do B Physics at a Hadron Collider => Trigger
- Some Run II Results from D0:
  - Exclusive B decays modes & Lifetimes
- Some Run II Results from CDF:
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  - Reconstruction of hadronic B decay modes

  (CDF's hadronic track trigger working well)
- More to expect with more luminosity

  (see talk on Bs mixing prospects by Stephanie Menzemer)

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"Anyone who keeps the ability
to see beauty
never grows old."
Franz Kafka
(born in Prague 1883)